Spin, pseudospin collective excitations in multilayer quantum Hall systems(Abstracts of Doctoral Dissertations,Annual Report(from April 2001 to March 2002))

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Summary

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In this thesis, we have studied quantum coherence phenomena in the bilayer quantum Hall systems. We have formulated systems based on the SU(4) scheme and discussed their symmetry breaking patterns and topological solitons. The condensation of the composite boson generates the quantum coherence in BLQH system. We have found that in BLQH system at a filling factor ν, the topological solitons are generally represented as Grassmannian solitons $G_{4,\nu}$.

The fifteen generators of SU(4) accommodate many different SU(2) generators. Accompanied with SU(4) approximate symmetry breakdown, the internal different SU(2) symmetries also break. At $\nu = 1$ BLQH systems, due to the breakdown of this SU(4) symmetry there arise three complex pseudo Goldstone modes, i.e. spin wave, ppin wave and ipin wave. The coherent topological excitations are $CP^3(=G_{4,1})$ solitons which are decomposed to three different CP^1 skyrmions called spin skyrmion, ppin skyrmion and ipin skyrmion. The ppin mode of the SU(2) breaking induces the Josephson-like tunneling current in BLQH system at $\nu = 1$. The tunneling current is comprised of composite bosons which have electric charge e.

In BLQH systems at $\nu = 2$, there are three possible ground states; spin phase, ppin phase and C-phase. We have argued the stability of C-phase. When the two layers are very close and the SU(4) coherence dominates, the C-phase almost vanishes and there remain only spin phase and ppin phase. We also investigate the low energy excitations in the spin phase and ppin phase. There are four complex pseudo Goldstone modes in each phase. The topological excitations are $G_{4,2}$ solitons. The fundamental excitations in the spin phase are spin and ipin waves and spin $G_{4,2}$ solitons. Similarly in the ppin phase, the fundamental excitations are ppin and ipin waves and ppin $G_{4,2}$ solitons. The ppin waves in the ppin phase induce the Josephson-like tunneling current also at $\nu = 2$.

In BLQH system at $\nu = 3$, three electrons exist per one Dirac magnetic flux. In other words, a hole exists per one Dirac magnetic flux. BLQH systems at $\nu = 3$ can be seen as hole systems at hole filling factor $\nu_h = 1$. Most discussions in BLQH systems at $\nu = 1$ go through in BLQH systems at $\nu = 3$ with the replacement of electrons to holes. The solitons are expected to be CP^3 solitons as in the $\nu = 1$ case. Actually we have confirmed solitons are $G_{4,3}=CP^3$ solitons. There are three different complex Goldstone modes and three different kinds of CP^1 hole skyrmions. The hole skyrmion carries charge $-e$, which is identified as the antiskyrmion in the electron picture. Therefore the soft waves and the topological excitations in BLQH systems at $\nu = 3$ are same as in BLQH systems at $\nu = 1$.

In BLQH system at $\nu = 4$, four electron states in the lowest Landau level are fully occupied with electrons. Four electron state becomes SU(4) singlet which doesn't have isospin degree of freedom. There are no isospin collective excitations at $\nu = 4$.

The generalization to the multilayer system is a straightforward task. In the N layer QH systems at the integer filling factor ν, the topological solitons are Grassmannian solitons $G_{2N,\nu}$ and real $2\nu(2N-\nu)$ pseudo Goldstone modes arise which are coordinates of the $G_{2N,\nu}$ manifold. The dimension of the $G_{2N,\nu}$ manifold is $\dim G_{2N,\nu}=2\nu(2N\text{-}\nu)$. While using the composite particle picture, the fractional QH systems may be understood much like the integer QH systems. For example, the BLQH systems at filling factor $\nu = \frac{2}{3}$ can be seen as the composite fermion bilayer system at composite fermion filling factor $\nu_{comp} = 2$. Then the discussions at $\nu = 2$ may apply. The Grassmannian solitons become anyons in fractional quantum Hall systems, which have a fractional electric charge and obey fractional statistics. The generalization of Grassmannian solitons in integer quantum Hall systems to solitons in the fractional quantum Hall systems is an interesting problem.

We have considered the physics much larger than the magnetic length ℓ_B and constructed a continuum effective theory to describe the infrared physics such as soft waves. However to be more precise, we have to analyze systems based on the noncommutative field theory. Grassmannian solitons may turn into noncommutative Grassmannian solitons. The observation of specific features stemmed from the noncommutativity is a future problem.